Reflectance Models

Outline

- Cook-Torrance Reflectance Model
- BRDFs
- Real-time BRDFs today
- nVidia BRDF Demo

Cook-Torrance Model

- Created in 1981
- Reflection components in older models (Phong, Blinn)
- Cook-Torrance: rough surfaces

Basics of Reflectance

- Light: energy per unit time or per unit area (flow)
- Bidirectional reflectance (R)

$$R = \frac{\text{Intensity of the reflected light}}{\text{Energy of the incident light}}$$

Bidirectional Reflectance

- Composed of two components
  - Specular
  - Diffuse

$$R = sR_s + dR_d$$

- What about ambient light?

Ambient light in Reflectance

- Ambient reflectance is independent of viewing direction
- Uniformly incident

  $I_{RA} = R_A I_{IA} f$

I_{RA}: Intensity of the reflected ambient light

R_A: Ambient Reflectance

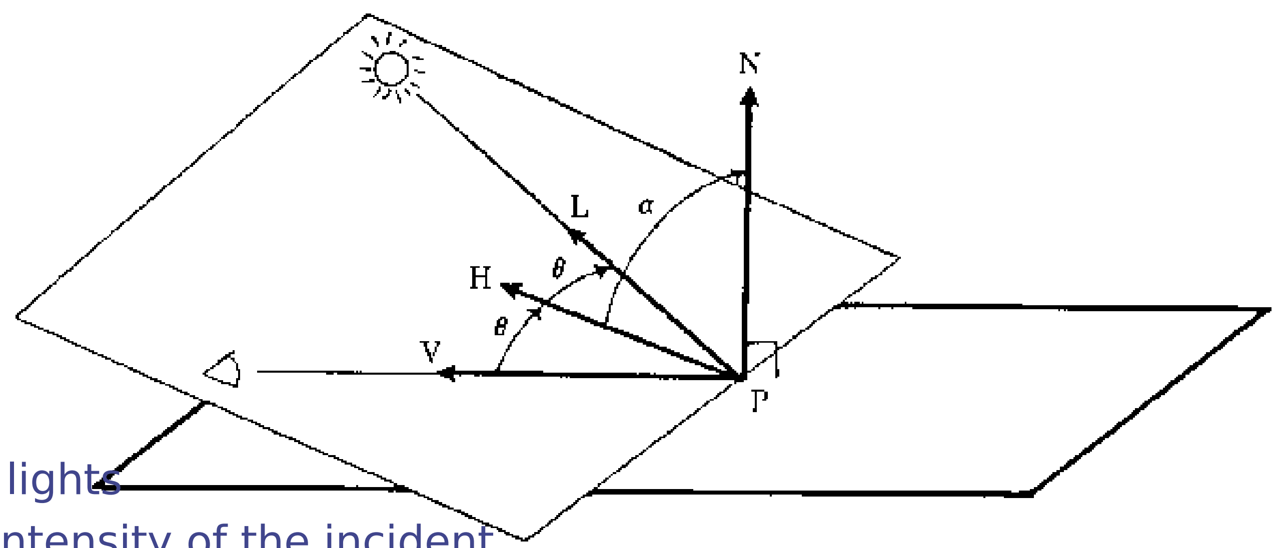
I_{IA}: Intensity of the incident ambient light

f: fraction of the illuminating hemisphere not blocked by objects

The MOVES Institute
Naval Postgraduate School

Intensity of Reflected Light

$$I_R = I_{lA}R_A + \Sigma_l \left(I_{il} \left(N \bullet L_l\right) d\omega_{il}\left(sR_s + dR_D\right)\right)$$



l: Individual lights

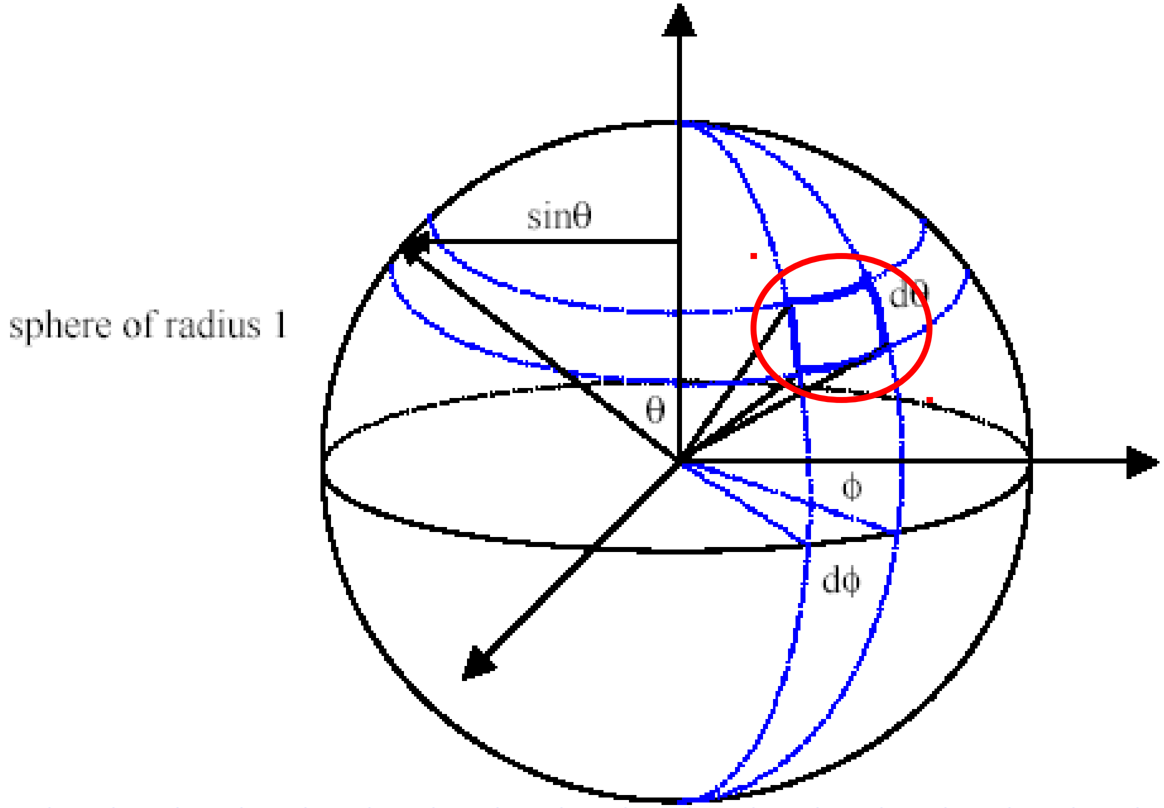
I_{il}: Average intensity of the incident light

N: Surface unit normal

L_l: Unit vector in the direction of light l

$d\omega_{il}$: solid angle of a beam of incident

Solid angle of Incident Light



Consequences

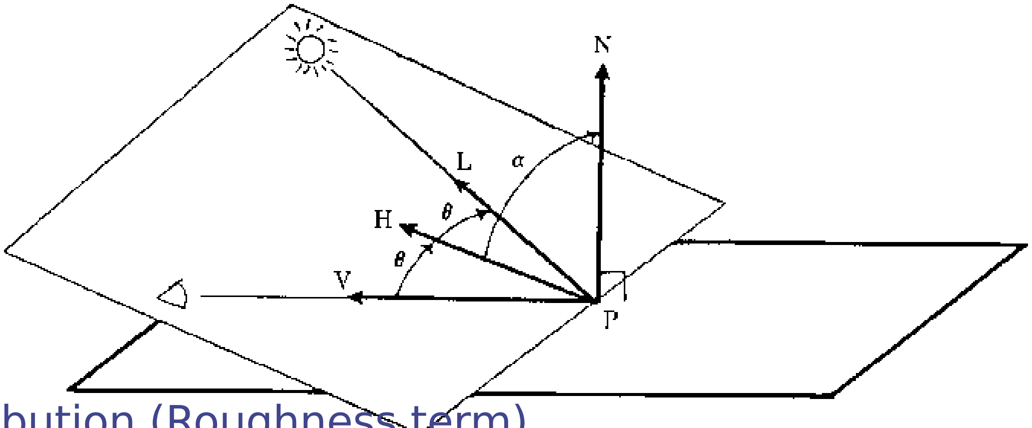
- Accounts for different intensities and different projected areas
- Does not consider the reflection of light from other objects in the environment
- Depends on:
  - Light wavelength (Intensities)
  - Material (s and d)
  - Geometry
  - Surface Roughness

Directional Distribution

- Ambient and diffuse reflection are direction independent
- Specular reflection is not
- Microfacet theory

Cook-Torrance's Contribution

$$R_s = \frac{F\,D\,G}{\pi\,(N \bullet L)\,(N \bullet V)}$$



F: Fresnel term

D: Facet slope distribution (Roughness term)

G: Geometrical attenuation factor

V: Unit vector in the direction of the viewer

Roughness Models

- Blinn provided one of the first models

$$D = ce^{-(\alpha/m)^2}$$

α: angle between H and N

(H: angular bisector of V and L)

m: root mean square (rms) slope of the facets

Roughness Models

- Beckmann improved on Blinn

$$D = 1/(m^2 \cos^4\alpha)\, e^{-(\tan^2\alpha/m^2)}$$

Blinn vs. Beckmann

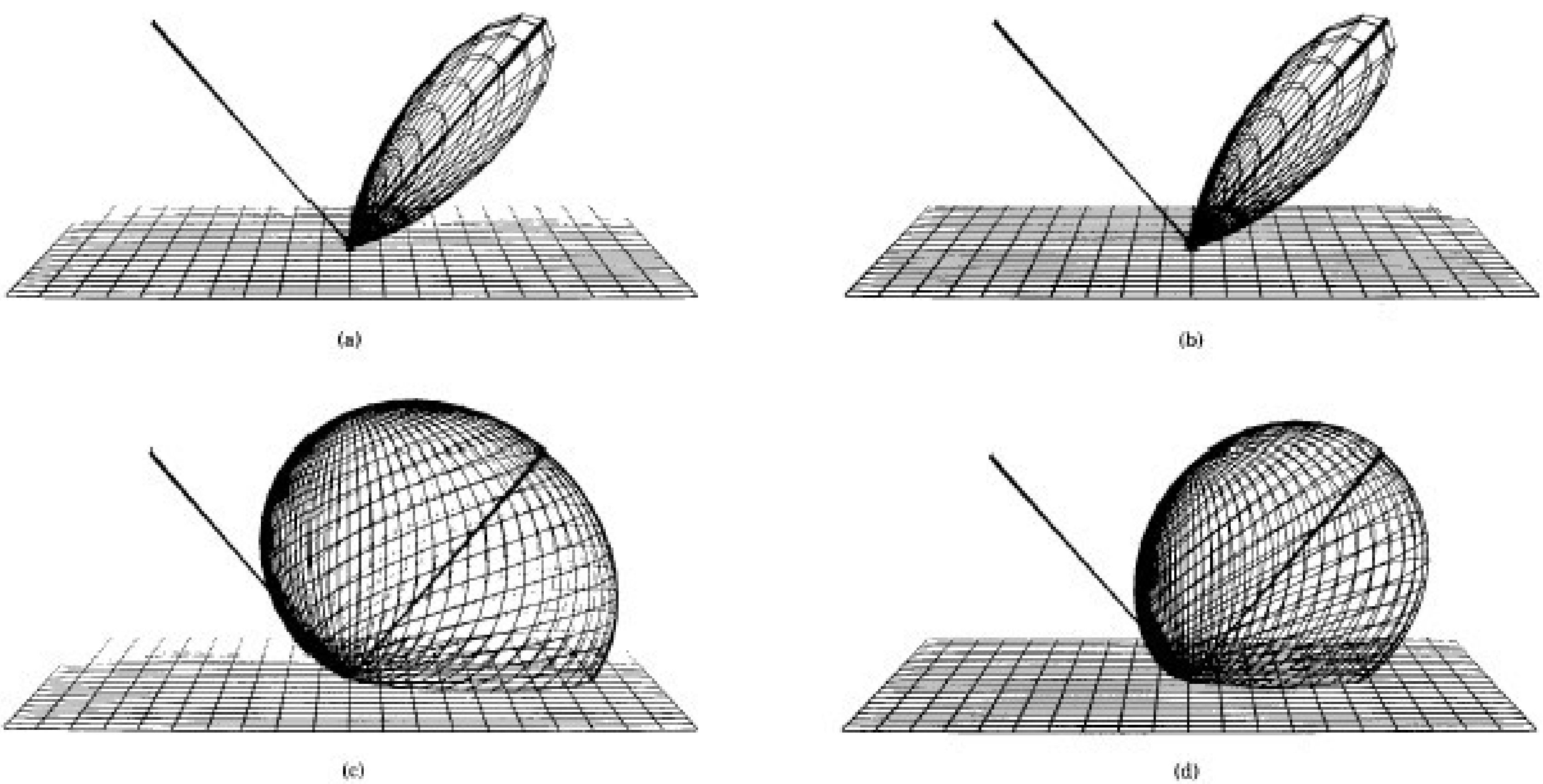
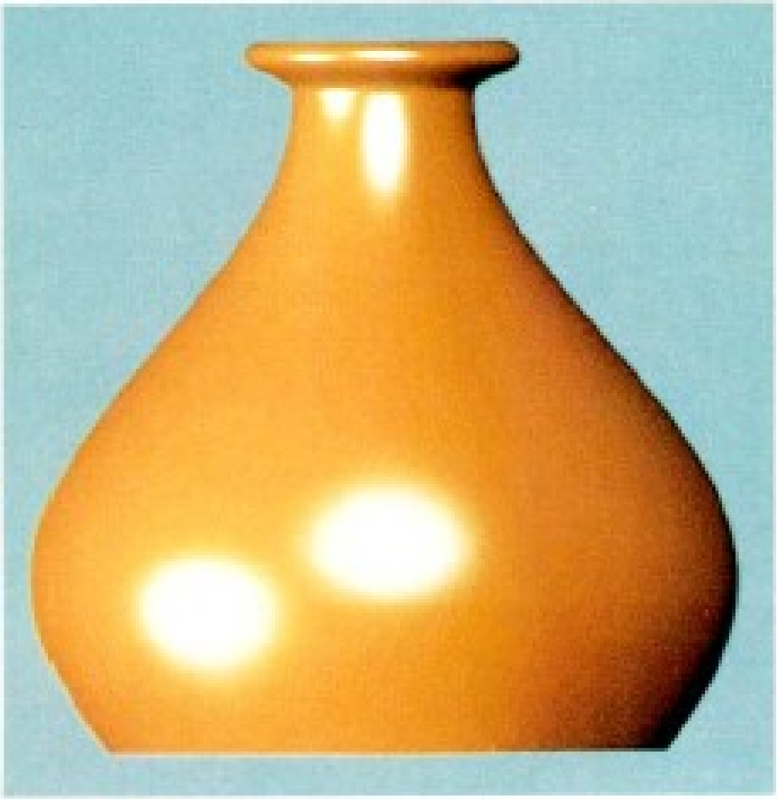


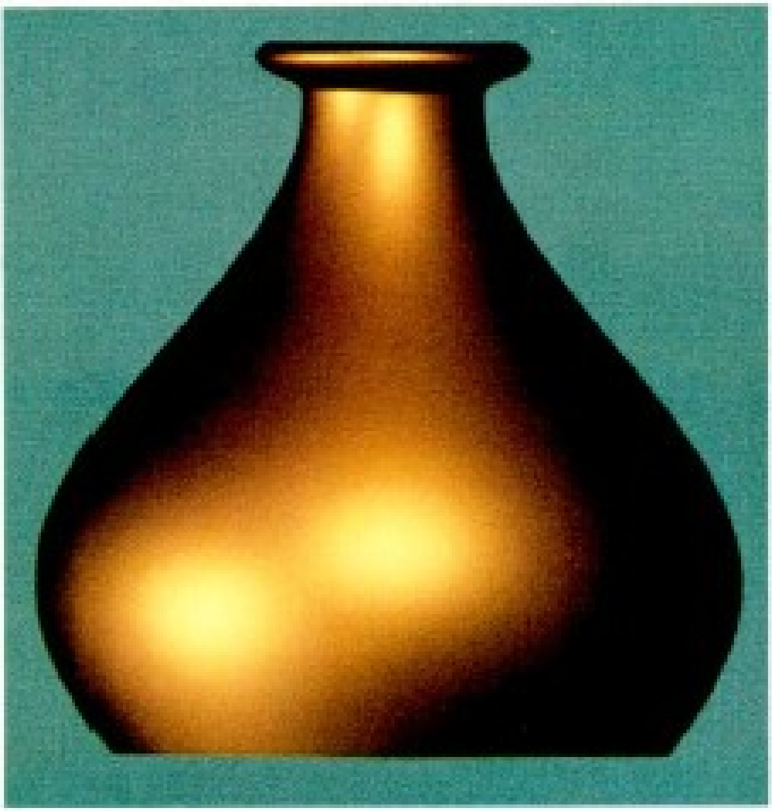
Fig. 3. (a) Beckmann distribution for $m = 0.2$, (b) Gaussian distribution for $m = 0.2$, (c) Beckmann distribution for $m = 0.6$, (d) Gaussian distribution for $m = 0.6$.

Results of Cook-Torrance

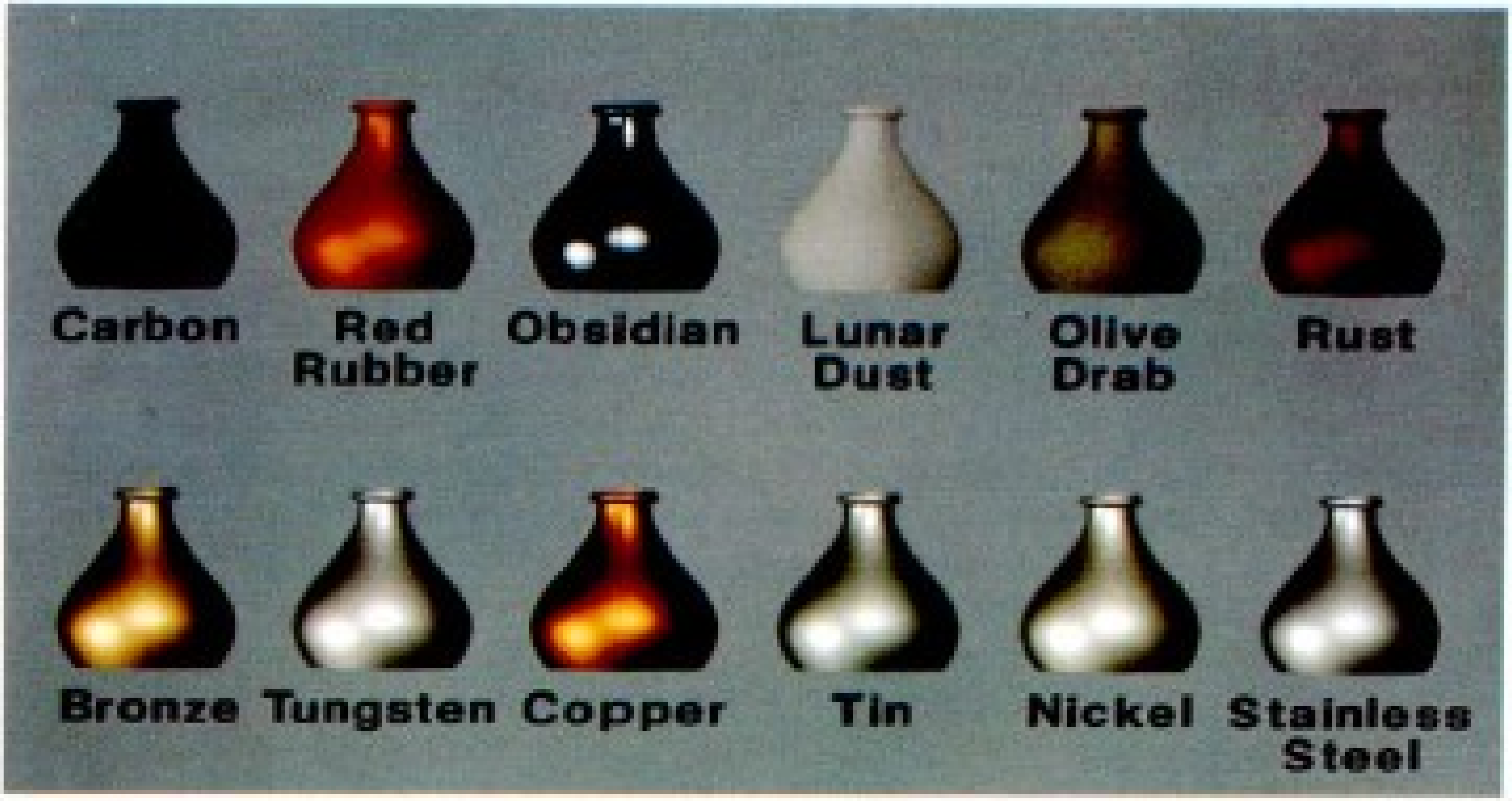
Copper colored plastic



Copper Vase



More cool results



BRDFs

- Incident light = reflected light + absorbed light + transmitted light
- What we see is reflected light
- Bi-Directional Reflectance Distribution Functions (BRDFs) describe the amount of reflected light

More on BRDFs

- Dependent on viewer and light position
- Example: specular highlights
  - Specular highlight moves as you change viewing position
  - Specular highlight moves as light source moves

More properties of BRDFs

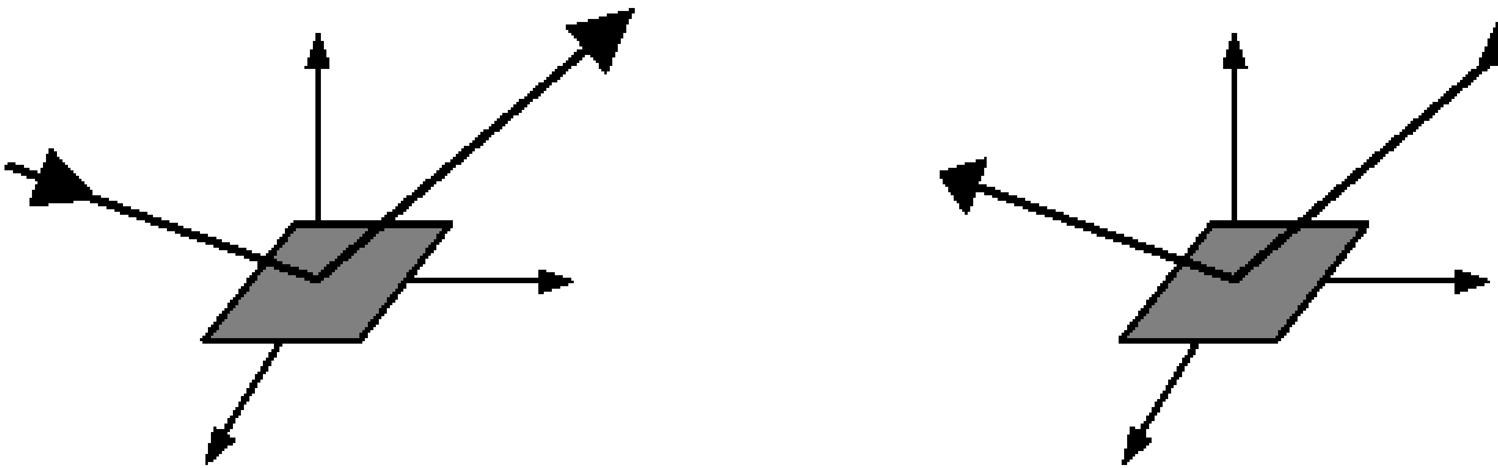
- Wavelengths of light absorbed, reflected, or transmitted as a function of the material's physical properties
- Light interacts differently across regions of a surface (grain of wood)

Type of BRDFs

- Isotropic
  - Reflectance independent of rotation about a given surface normal
  - Smooth plastics
- Anisotropic
  - Reflectance changes with rotation around a given surface normal
  - Brushed metal, satin, hair

Properties of BRDFs

- Reciprocity



From “An Introduction to BRDF-Based Lighting” by Wynn

Properties of BRDFs

- Conservation of Energy

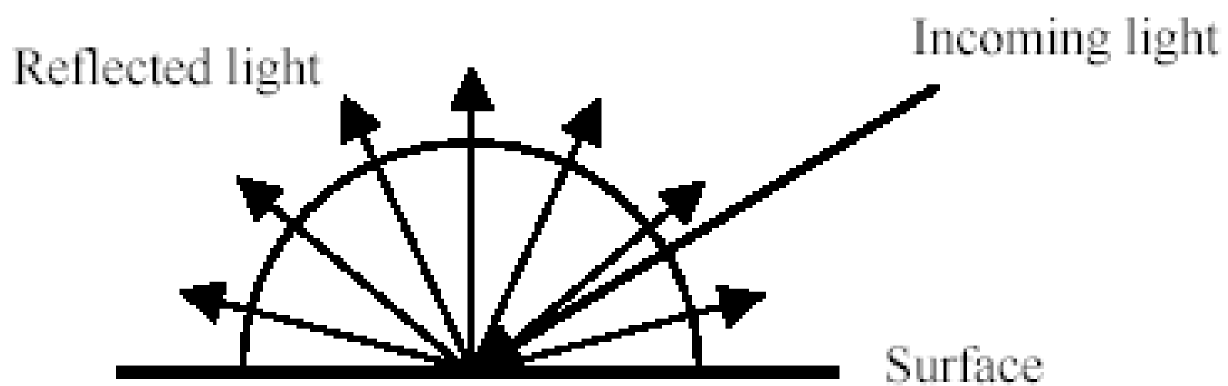
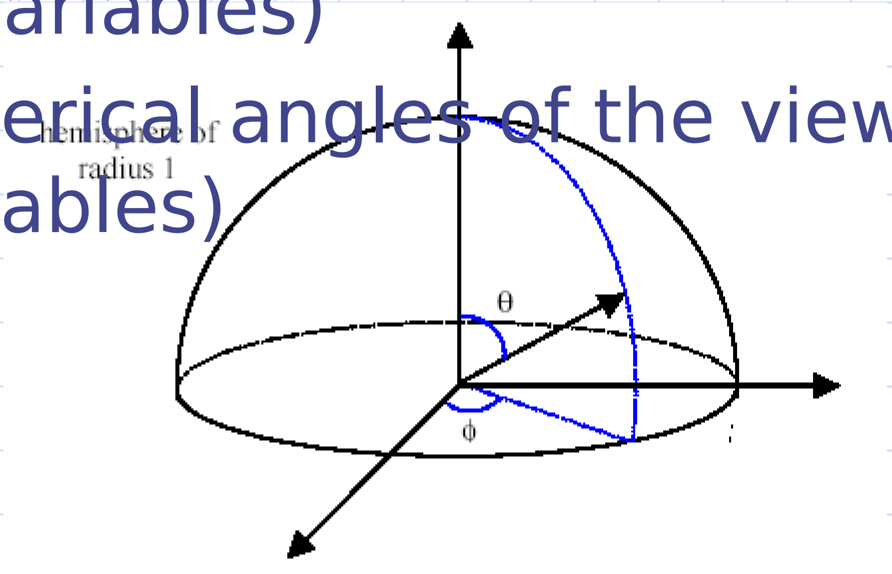


Figure 7. Conservation of Energy- The quantity of light reflected must be less than or equal to the quantity of incident light.

From "An Introduction to BRDF-Based Lighting" by Wynn

Real-time BRDFs

- BRDFs are a function of 4 variables:
  - Spherical angles of the incident light (2 variables)
  - Spherical angles of the viewer (2 variables)



Real-time BRDFs

- Split the 4-dimensional function into 2 2-dimensional functions (pairs of 2D texture lookups)
- Two phase rendering
  - Preprocessing: splitting the function
  - Runtime: reconstructing BRDF and computing BRDF lighting
- Want to know more?

Real-Time BRDF-based Lighting using Cube-Maps by Chris Wynn

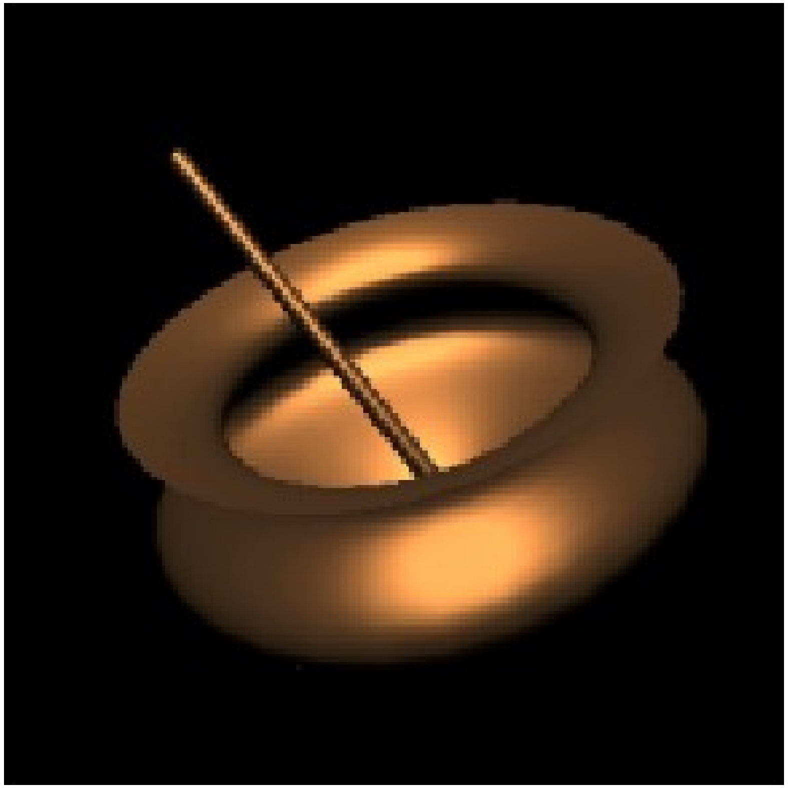
Results of this technique

a) Anisotropic Gold BRDF using GSHD parameterization.

b) Anisotropic Gold BRDF using OI parameterization.

More cool results

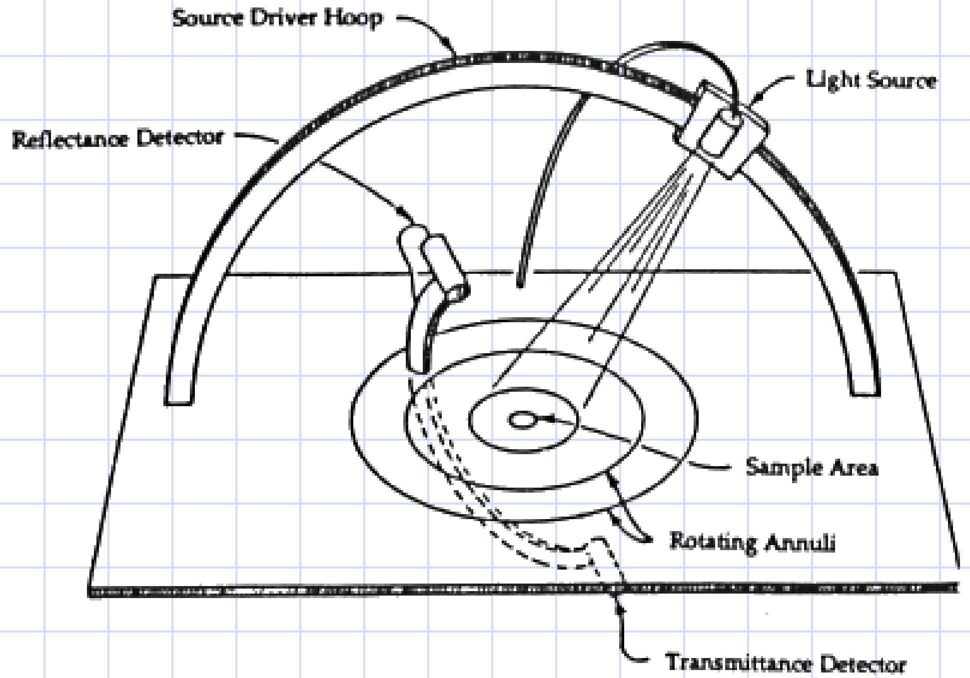
c) Anisotropic plastic BRDF using GSHD parameterization.



d) Bronze BRDF using GSHD parameterization.

Other methods for BRDFs

- Direct measurement
  - Gonioreflectometer



Other methods for BRDFs

- Direct measurement con't

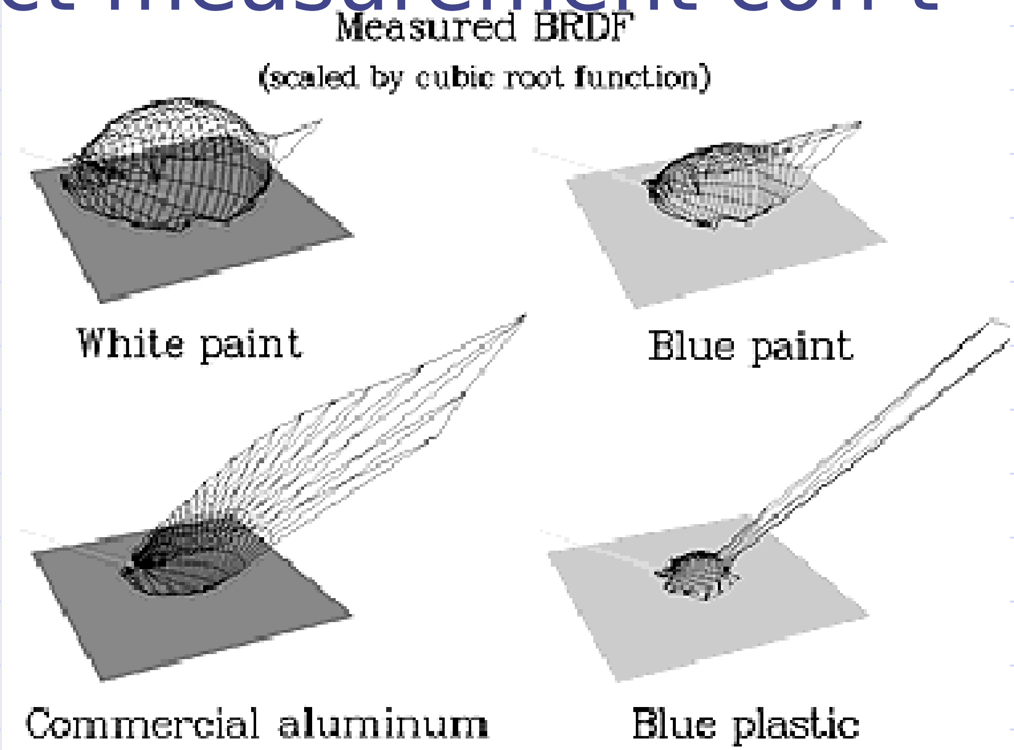


Figure 8: *Measured BRDF for four isotropic materials.*

Taken from "A Framework for Realistic Image Synthesis" by Greenberg, et. al. (Cornell)

Microfacet theory

- Way to model the light reflecting off all of the irregular shapes of a

nVidia BRDF Demo

- Gram-Schmidt Halfangle-Difference vector parameterization
- Real-time technique mentioned earlier
- Ability to show the two different textures that are combined to create the final image

Questions?

References

- Robert L. Cook and Kenneth E. Torrance, "*A Reflectance Model for Computer Graphics*" from *Proceedings of SIGGRAPH '81*, p. 307-316
- Chris Wynn, "An Introduction to BRDF-Based Lighting" from nVidia website
- Chris Wynn, "Real-Time BRDF-based Lighting using Cube-Maps" from nVidia website
- Szymon Rusinkiewicz, "A Survey of BRDF Representation for Computer Graphics," Stanford University, 1997